Simulating How the Wind Blows

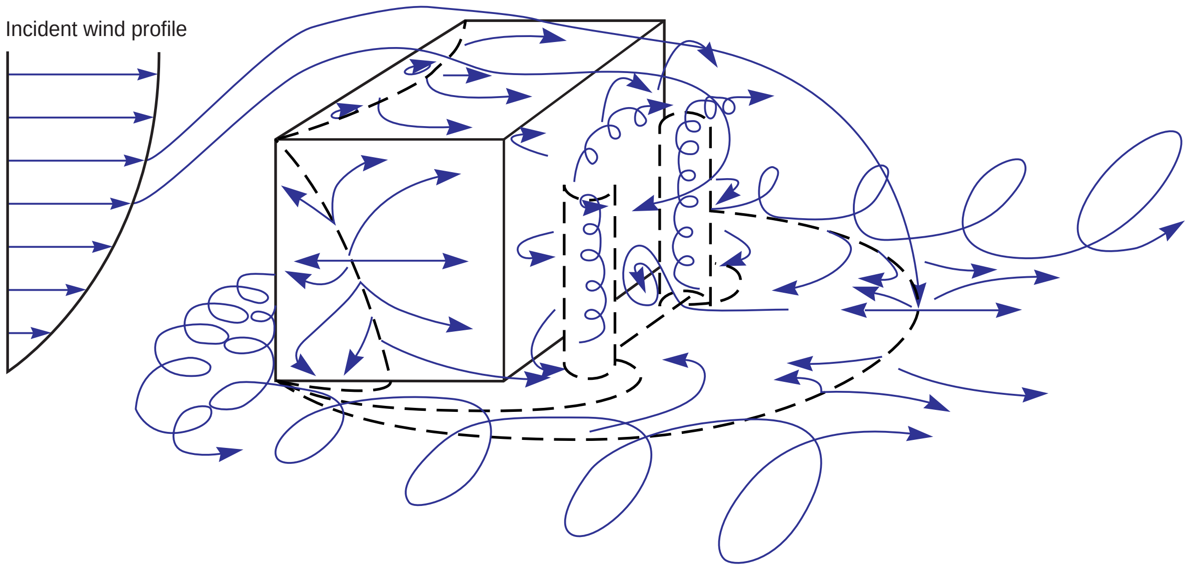
ANALYZING and simulating atmospheric transport and dispersion is the stock in trade of Livermore's National Atmospheric Release Advisory Center (NARAC). In 1986, NARAC took on its first big test and successfully predicted the path that radioactive contaminants from the Chernobyl nuclear plant explosion would take across the USSR and Europe. Since then, NARAC has analyzed dozens of other chemical and nuclear accidents around the world. Understanding wind flow and turbulence in the atmosphere is at the heart of being able to predict the transport and dispersion patterns of atmospheric releases.

Those complex analyses were on a large regional or even global scale. Understanding how particles or gases move on a smaller scale is more difficult. The movement of a gentle breeze, for example, is not as simple as it looks. Trees, buildings, walls, fences, and the like cause eddies and other changes in the direction and speed of the breeze. A single building can create astonishing changes in flow patterns.

These small-scale effects matter for atmospheric scientist Bob Lee and colleagues Ron Calhoun, Steve Chan, John Leone, and Dave Stevens. They form a team that is seeking to understand and predict the behavior of biological and chemical agents released into the atmosphere within urban areas. Their work is part of Livermore's contribution to the Department of Energy's Chemical and Biological National Security Program.

Modeling and analysis of airflow and dispersion in urban settings may be done on three different scales, each of which can "see," or resolve, details at varying levels. The domains of the three scales are nested, with the highest spatial resolution at the smallest scale. At that smallest scale, the highly resolved simulation is of a single building or a few buildings, with a domain size of a few square kilometers and a time scale of a few minutes. The mid-range scale involves many buildings, tens of kilometers, and a dispersion time of one or two hours. These simulations can identify only clusters of buildings rather than individual buildings. The largest scale is urban/regional, which encompasses an entire urban and suburban area. Its size, as large as several hundred square kilometers, corresponds to the area of a typical regional weather forecast; the dispersion times may be many hours.

Lee and his colleagues have developed a finite-element-based computational fluid dynamics (CFD) modeling code known as FEM3MP. The code can handle either buoyant or heavier-than-air releases as well as processes involved in aerosol physics, bioagent viability degradation due to ultraviolet light, and surface heating and shading. FEM3MP treats buildings explicitly and incorporates parameters to



Developing atmospheric models for an urban setting requires taking many flow patterns into consideration. Flows around buildings are complex, with separation and stagnation zones, turbulent wakes, and vortices.

account for tree canopies. The simulations generated by FEM3MP represent turbulent air flow and the influence of atmospheric stratification on dispersion patterns within urban and surrounding areas.

Huge computers, especially the massively parallel machines of the Accelerated Strategic Computing Initiative (ASCI), have made it possible for models to incorporate a high level of detail and yet process calculations quickly. "We have been modeling atmospheric flow and dispersion since the early 1980s," says Lee. "Much of our work has been in emergency response planning, which until recently had to rely on simple models. Not any more."

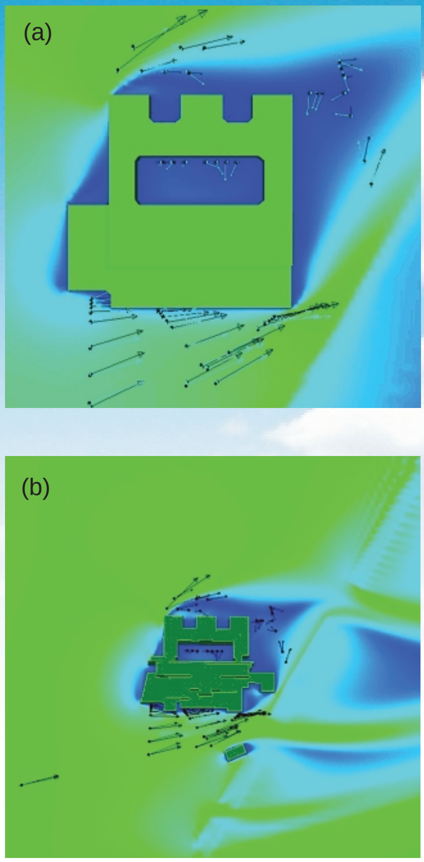
Testing the model in the real world to assure its accuracy is as important as developing the model in the first place. Validation studies for urban air flow and dispersion models can be done in a wind tunnel as well as in the field, with real buildings. The first validation experiments for FEM3MP were conducted in a wind tunnel using blocks to represent buildings. The model simulations reproduced many important flow features such as separation zones, recirculation cavities between buildings, and interacting turbulent wakes. Only a sophisticated CFD model, such as FEM3MP, can capture these detailed flow features with sufficient accuracy.

Just One Building

Members of Lee's team didn't have to look far to test their model on a single building. They chose Livermore's Building 170, home of NARAC, where most of them have offices. First, they ran FEM3MP to predict wind patterns around the building. This information told the field team where to place their instrumentation, consisting of about a dozen wind sensors that they moved to various locations around the building over a period of several months. They also made a few releases of an inert, harmless, odorless gas and tracked its evolution with remote sensing equipment and in situ instrumentation.

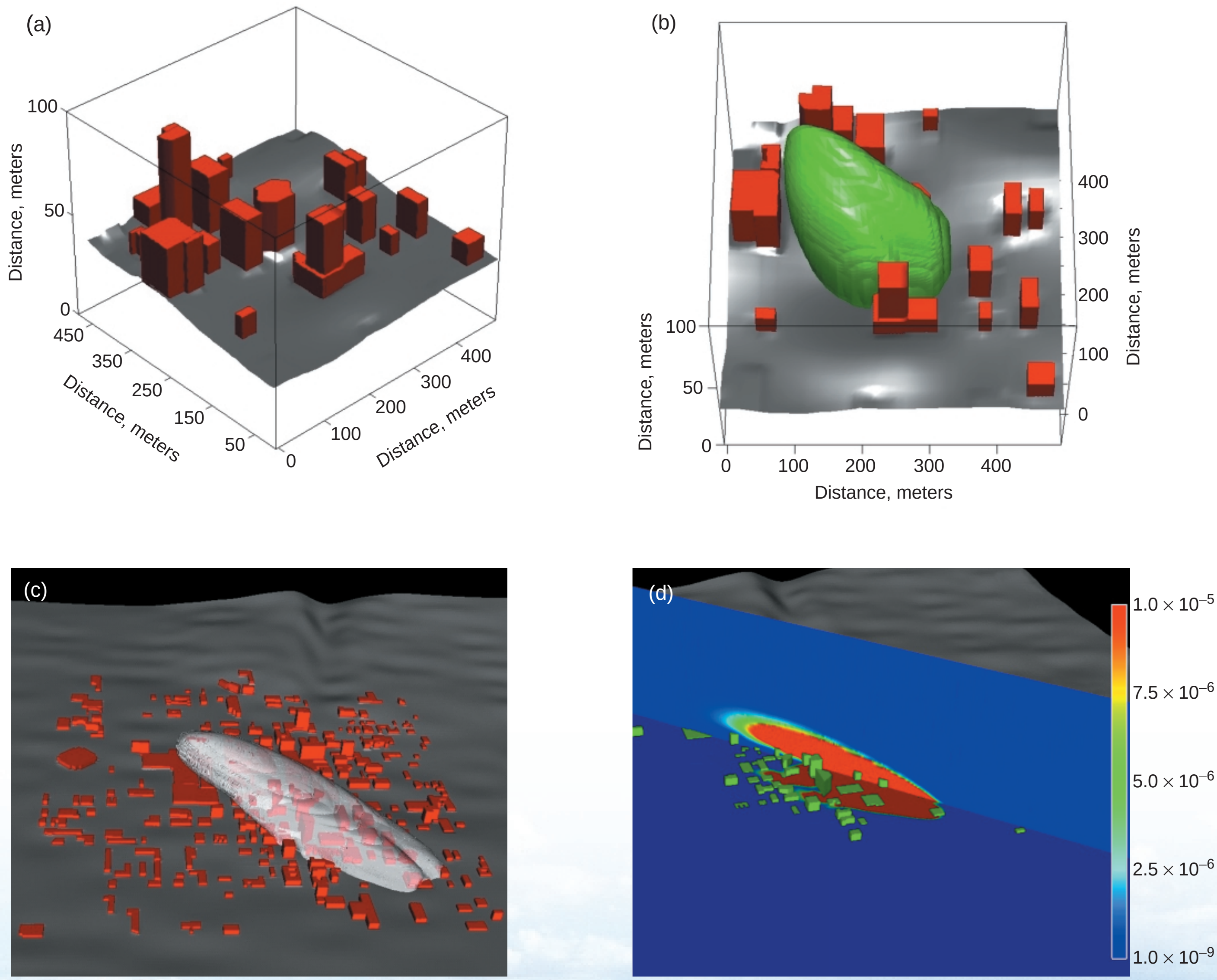
The team's databank of experimental information from wind sensors and gas measurements then supplied the basis for a much improved model simulation—the "postexperiment" model simulation—of air flow around Building 170. Long-term meteorological data showed that the prevailing mean wind during the summer when the experiments were performed was out of the southwest. The top figure at the right compares the preexperiment and postexperiment simulations with actual field data for this case.

Lee and his colleagues found their models to be remarkably accurate, to within 10 percent for wind directions and



Researchers improved their air dispersion models when they incorporated field experimental data on wind patterns to calculate the consequences of gaseous releases into the models. The difference in simulation results is apparent in a comparison of (a) the preexperiment simulation with (b) the postexperiment simulation, which is much more complex and more accurately represents the details of the building.

Wind sensors were set up at various locations around Building 170 at Livermore to collect information about wind patterns.



One simulation of the surface release of a generic tracer gas in downtown Salt Lake City. (a) Graph of the buildings within a 500-meter by 500-meter area near the source of the release. (b) An aerial view of the tracer plume over the greater downtown area 400 seconds after the release. (c, d) Cross-sectional views of the same plume showing the horizontal and vertical spread for the range of concentration depicted.

15 percent for wind speeds. The models successfully simulated many detailed flow features, such as the shedding of vortices from corners of the building and the blockage effect caused by a nearby row of 9-meter-tall eucalyptus trees. One of the most interesting simulations was one that used measured, second-by-second upwind data to "drive" the model calculation. This combination of experimental data and modeling represents a first step in the fusion of model and field data.

An Urban Scene and Beyond

Late last year, DOE completed an ambitious field experiment of atmospheric flow and dispersion in Salt Lake City, Utah. Livermore was a leader and major participant in the experiments and provided model simulations to the field team so that it would know where to place instrumentation.

Several DOE organizations, other federal agencies, and universities collaboratively collected field data relevant to all three scales of modeling, from a single building to the Salt Lake City basin to the entire region. Livermore used FEM3MP to generate flow and dispersion results for both the building scale and the basin scale. COAMPS (Coupled Ocean/Atmosphere Mesoscale Prediction System), a code developed by the Naval Research Laboratory and adapted by NARAC, provided forecasts for the regional scale. For the building scale, modeling focused on the effects of individual buildings or clusters of buildings. The basin scale modeling focused on terrain and thermal effects, in particular the air flows from the mountains east of Salt Lake City. The largest scale focused on regional-scale meteorology, within an area that includes parts of Idaho and Wyoming.

All of the simulations were massive, some with up to 100 million grid points. This work—simulating small-scale weather patterns and the dispersal of a tracer gas in the Salt Lake City area—especially benefited from the full computational power of the ASCI White computer. The building-scale exercises modeled up to 500 buildings to produce state-of-the-art, high-resolution simulations of air flow and dispersion. The figure on p. 18 shows views of some of the simulations.

"The Department of Energy is making a sizable investment in the computational-fluid-dynamics approach to urban dispersion modeling," says Lee. DOE's goal is to develop validated, multiscale computational models that support emergency preparedness, response, and detection of biological and chemical releases in urban areas.

—Katie Walter

Key Words: Accelerated Strategic Computing Initiative (ASCI), atmospheric dispersion, biological and chemical agents, Chemical and Biological National Security Program, computational fluid dynamics (CFD), National Atmospheric Release and Advisory Capability (NARAC), urban dispersion modeling.

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